VACUUM BRAZING OF THE NEW RFQ FOR THE J-PARC LINAC

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Abstract

The fabrication of a new RFQ has been started as a backup machine for the J-PARC linac. The RFQ cavity is divided into three unit tanks in the longitudinal direction. Each unit tank consists two major vanes and two minor vanes which are brazed together. A one-step vacuum brazing procedure for the unit tanks was adopted to integrate the four vanes together with the accompanying flanges and ports. At the first brazing attempt, a vacuum leak developed probably due to a non-uniform temperature rise during the heating. The repair of this leak and the results of the improved brazing scheme for the second tank are reported.

INTRODUCTION

The J-PARC RFQ is a four-vane type cavity to accelerate negative hydrogen beam from 50 keV to 3 MeV with a peak current of 30mA. The length of the RFQ cavity is 3.2 m and the operating frequency is 324MHz. The RF duty factor is 3% (600 μs at 50 Hz).

We started building an RFQ as a backup ready for quick replacement in case of a catastrophic RFQ operation trouble. The beam dynamics design is the same as that for the current RFQ. However, the mechanical design has been changed. The engineering design work began at the beginning of 2009. The fabrication began last summer [1, 2].

Vacuum brazing is used to join the vanes. Usually the ports and flanges are brazed after the vane brazing. We tried to integrate everything, vanes, ports, and flanges with a one-step brazing to reduce the fabrication process steps and cost. However, at the first tank brazing attempt, the vacuum leak developed. Therefore, we improved the method of folding the flanges, and the brazing temperature control.

In this paper, we will describe the results of this brazing series and the repair of the vacuum.

DESIGN OF THE RFQ AND THE BRAZING

The RFQ cavity is divided longitudinally into three unit tanks. Each tank (about 1 m long) consists of the major and the minor vanes, which are brazed to each other. Mechanical design features are listed in Table 1. The vanes are machined by numerical-controlled machining with a ball-end-mill[3], and chemically polished to obtain a smooth surface before the brazing.

Table 1: Mechanical Design Features

Material	High-purity oxygen-free copper with HIP(Hot Isostatic Pressing)
Drilled hole plugging	Electron beam welding (EBW)
Annealing	600 degrees C in a vacuum furnace
Vane machining	Numerical-controlled machining with a ball-end mill
Surface treatment	Chemical polishing (3-5μm)
Integration method	Vanes and ports are jointed in a one step brazing
Unit cavities connection	Welding for the vacuum seal, bolting for mechanical alignment

VACUUM BRAZING

Figure 1 shows a schematic drawing of the unit cavity components to be assembled for brazing. The vanes are aligned with each other along the outer lateral plane, and then they are fixed together using bolts made of SUS304. Ports and flanges are bolted onto the cavity. The cavity is put into the furnace in its normal horizontal orientation. The brazing alloy is Ag72-Cu28. The maximum temperature for the brazing is set to be 790 degrees C, which is measured by thermocouples (TCs) distributed around the cavity.

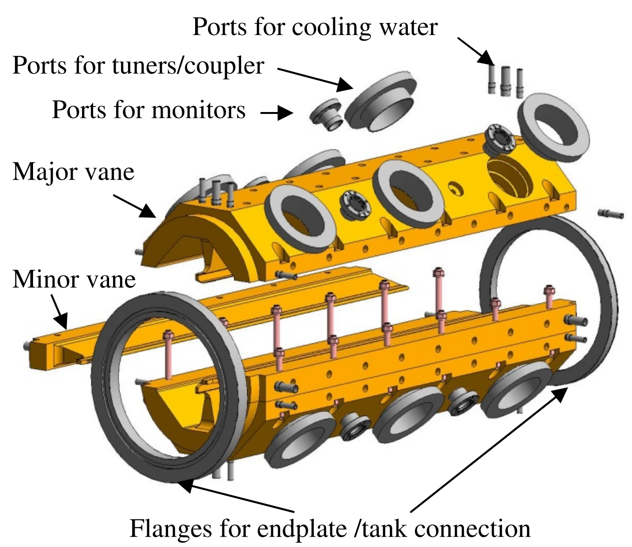

Figure 1: Schematic drawings of the vanes of the unit tank.

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Results from the First Unit Brazing

After the brazing, the resonant frequency of the operating mode was 0.26MHz higher than that before the brazing. The Q-factor increased from 6800 to 9400, which is 87 % of the expected value from the Superfish calculation.

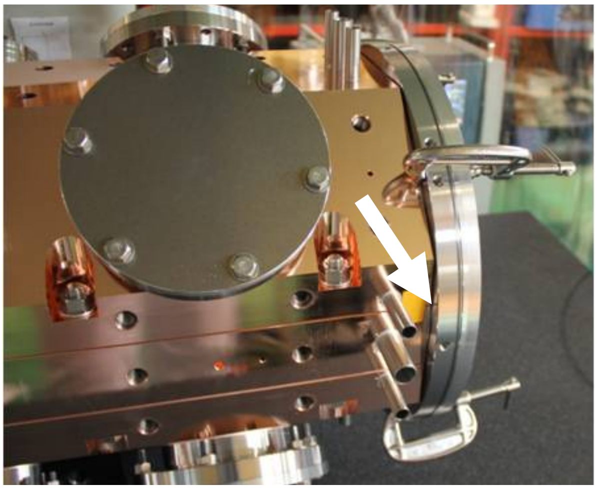
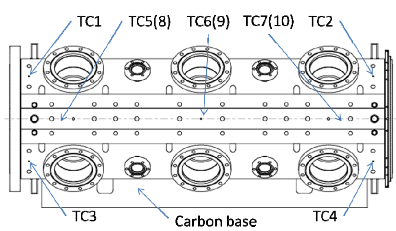


Figure 2: The vacuum leak at the stainless-steel flange.



TC locations

(numbers in parenthesis on opposite side)

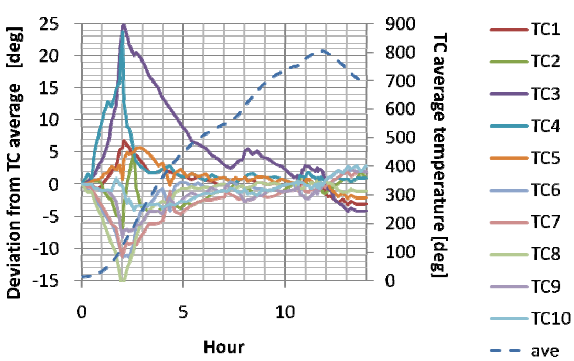


Figure 3: Temperature distribution during the brazing. Dashed line (right scale) is the average temperature of all TCs. The other lines (left scale) are the deviation of each TC from the average temperature.

We found the vacuum leak at the stainless-steel flange location indicated in Fig. 2. We speculate that nonuniform heating during the brazing was the cause. The heating speed of the vacuum furnace was set to be 300 degrees C/h from the room temperature up to 600 degrees C. This heating speed may have been too fast for uniform heating of the vanes. Figure 3 shows the measured temperature from the TCs set on the cavity. The dashed line is the average temperature of all the TCs; the other curves are the deviation of each TC from the average temperature. The temperatures measured by TC3 and 4 (the bottom major vane) are momentary higher by about 40 degrees C over the other vanes at the beginning of the brazing.

We think that the leaking flange was pushed out by the unequal differential thermal expansion of the vane and then brazed at a mismatched position. We tried re-brazing by putting additional brazing alloy near the leak, however, the vacuum seal failed. We then removed the stainless-steel flange with a dry-cutting method and re-brazed. The method of securing the stainless-steel flange was changed from the staking to bolting with a compression spring. The spring is made of a carbon fiber composite. The strength of this spring is constant in a temperature range up to 1000 degrees C.

After the re-brazing of this flange, another vacuum leak was found at one of the welding spots. The cooling channels were drilled with a gun-drill and plugged by electron-beam-welding (EBW). Each unit cavity has 24 welded plugs. The depth of fusion by welding is more than 5 mm and the width of the weld bead is around 4 mm. In the fabrication procedure, the EBW took place before the annealing. The weld bead on the surface was removed at the final machining to a depth of 0.5 mm. The first unit tank under went three brazing heat cycles in all because of the flange leak repair. Taking that into consideration, we think that this leak near a weld bead was caused by a crack induced by these heat cycles. After this leak was finally repaired by another EBW, no more vacuum leaks were found.

Results from the Second Unit Brazing

At the brazing of the first unit, the major vane in the bottom position became hotter than the other vanes. The heat flow from the carbon base (where the blackness and thus temperature is higher) should be decreased. Therefore, we put ceramic spacers between the bottom

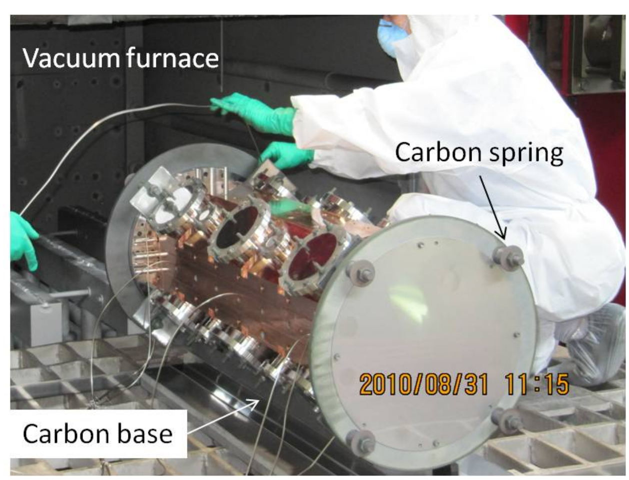
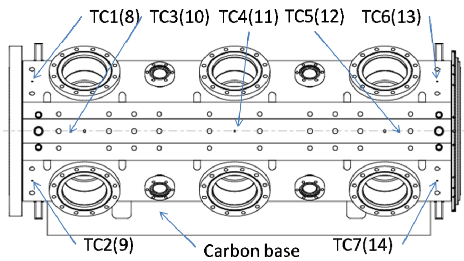


Figure 4: Setting the TCs on the cavity to monitor the temperature during the brazing.

face of the cavity and the carbon base, and in addition the carbon base was covered by a stainless-steel plate.

The heating speed of the furnace was slowed down and manually controlled to realize a uniform temperature distribution over the vanes. Figure 5 shows the measured temperature of the TCs during this brazing process. As before, the dashed line is the average temperature of all the TCs but the other curves are the deviation of vane temperatures from the average of all TCs. The vane temperature comes from averaging the TCs in each vane.



TC locations

(numbers in parenthesis on opposite side)

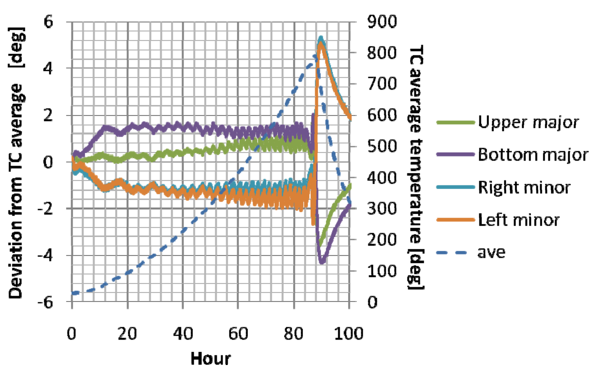


Figure 5: Temperature distribution during the second unit brazing process. Dashed line (right scale) is the average temperature of all the TCs. The other lines (left scale) are the deviation of the vane temperature from the average.

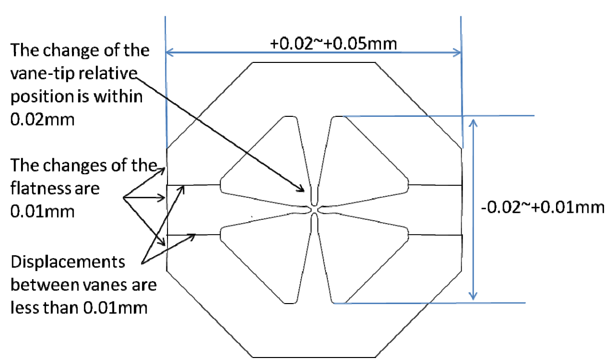


Figure 6: Deformation after the brazing. Inner height is measured at the both ends of the unit cavity.

During the heating, the maximum temperature deviation was typically 5.5 degrees C. The heating speed of the furnace was made as slow as 10 - 50 degrees C/h while the temperature was less than 600 degrees C, however, the deviation increases during the heating. Then, the heating speed was manually controlled. The comb-like fluctuation is coming from the furnace temperature control. The largest deviation was about 9 degrees C at the cooling phase just after the final heating.

After the brazing, it is confirmed that the vacuum seal was good. The deformation and the displacement are in the tolerable range. Figure 6 shows the deformation after the brazing as measured by CMM. Displacements between vanes are less than 0.01 mm. The deformation of the major vane is about 0.05 mm. The change of the vane-tip relative position is within 0.02mm, which is mainly due to the deformation of the major vane.

The Third Unit Brazing

During the second unit brazing, a clear tendency in the temperature differences between vanes can be seen in Fig. 5. The temperatures of the minor vanes are lower than those of the major vanes. The ratio of the outer surface area to the volume of the minor vanes is smaller than that of the major vanes. Therefore, this could cause the rate of temperature increase to be different between the major and minor vanes. Based on this assumption, we will try to put heat absorbers on the minor vanes to speed up their rate of temperature increase. In addition, the temperature of the lower major vane is slightly higher than that of the upper major vane, so that we will enhance the thermal shield for the carbon base.

SCHEDULE

We finished brazing the second unit at the beginning of Sept. 2010, the final unit brazing is scheduled for this Oct. After the assembling of the unit cavities, ducting, tubing, and cabling, the high-power test will be conducted.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Y. Iino, Mr. H. Hatanaka, and Mr. A. Iino of Toyama Co., Ltd. for the mechanical design. The authors would also like to thank Mr. T. Shimada, Mr. T. Uno, and Mr. T. Suzuki of Metal Technology Co., Ltd. for the brazing of this RFQ.

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